REPORT - FAA - RD - 72-21

EVALUATION OF WARM-FOG ABATEMENT CHEMICALS

E. E. HINDMAN, II, R. S. CLARK
NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA 93555

transpo 72
U.S International Transportation Exposition
Dulles International Airport
Washington, D.C.
May 27-June 4, 1972

FEBRUARY 1972
FINAL REPORT

Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151 for sale to the public

Prepared for

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
Washington D C 20591

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Department of Transportation. This report does not constitute a standard, a specification or a regulation.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-72-21		

4. Title and Subtitle
Evaluation of Warm-Fog Abatement Chemicals

5. Report Date
February 1972

6. Performing Organization Code

7. Author(s)
E. E. Hindman, II and R. S. Clark

8. Performing Organization Report No.

9. Performing Organization Name and Address
Naval Weapons Center
Code 6022
China Lake, California 93555

10. Work Unit No.

11. Contract or Grant No.
DOT FAA72WA1-250

12. Sponsoring Agency Name and Address
Department of Transportation
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, D.C. 20590

13. Type of Report and Period Covered
Final Report, October 1971 - February 1972.

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Dow Chemical Company demonstrated that glycerine, diethylene- and tetraethylene-glycol ~~were promising~~ as warm-fog abatement chemicals. The FAA requested that the fog-abatement properties of these chemicals be evaluated during the NWC Project Foggy Cloud IV, Humboldt County, California.

Only one fog-abatement test was conducted using glycerine because of a lack of fog during the test period. Nineteen micron glycerine droplets were sprayed at 21 gal/acre into a 250 ft deep stratus deck from a tethered hot-air balloon. The results indicated that the heat from the balloon cleared the first 50 ft of the deck and the glycerine droplets cleared a 178 ft diameter hole through the remaining 200 ft. The droplets cleared the hole by reducing the relative humidity in the stratus deck which caused the stratus droplets to evaporate.

17. Key Words
Warm fog
Fog-abatement chemicals
Glycerine

18. Distribution Statement
Availability is unlimited. Document may be released to the National Technical Information Service, Springfield Va. 22155, for sale to the public.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	31	3.00 pc .95 MF

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Details of illustrations in
this document may be better
studied on microfiche

INTRODUCTION

The Naval Weapons Center, China Lake, California has been conducting a laboratory and field program for improving visibility in warm fog. This work began in 1963 on a limited basis. Project Foggy Cloud I was initiated in 1968 and resulted in the identification of a hygroscopic agent consisting of ammonium nitrate-urea and water (see Blomerth, et al., 1970; Clark, et al., 1971). Project Tule Fog, conducted in early 1969 at NAS, Lemoore, California (see White, et al., 1969), further demonstrated the fog clearing properties of this agent. This work was continued later in 1969 with Project Foggy Cloud II. It was found that 94% of the fogs treated with the solution showed clearing effects and 67% of the treated fogs had visibility improvements sufficient to permit aircraft operations (see Wright, et al., 1972). Project Foggy Cloud III, in 1970, led to improved seeding techniques using the ammonium nitrate-urea-water solution (see Wright, et al., 1972a). This project demonstrated that 90% of the treated fogs showed clearing effects, and 100% of the fogs with steady-state conditions 1/2 hour prior to seeding had visibility improvements sufficient to permit aircraft operations. St.-Amand, et al. (1971) reported that average ceiling and visibility improvements in these "steady state" fogs were 214 feet and 1 1/16 mile, respectively. During Project Foggy Cloud IV in 1971, it was learned that the hygroscopic solution seeding technique from a fixed-wing aircraft is superior to water or using fixed-wing distrails with water (see Hindman, et al 1972).

Results from this project have suggested that certain critical meteorological conditions strongly influence the clearing of warm fog with the solution from a fixed-wing aircraft (Hindman, 1972). Investigations are underway to define the microphysical structure of the type of warm fog encountered during this project (Hindman, 1972a).

Carroz, et al. (1972) estimate that electrically charged droplets would have enhanced fog clearing capability as compared to uncharged droplets. As a result, during Project Foggy Cloud IV, charged droplets were sprayed from a hot-air balloon into a small volume of fog, thus permitting "laboratory type" experiments to be conducted in the field (see Loveland, et al., 1972).

The FAA requested that chemicals such as glycerine, diethylene- and tetraethlyene-glycol, proposed and furnished by Dow Chemical Company, be tested using the hot-air balloon.

The hot-air balloon system is depicted in Figure 1. The balloon carried 30 gallons of the test chemical in the gondola. The chemical was sprayed from the gondola using the Dow particulator (see McDuff, et al., 1971). The cable hanging below the gondola carried power to the balloon and supported a verticle array of droplet samplers. These samplers were used to determine if the droplets of chemical changed in size by accretion of the visibility restricting droplets or of water vapor.

Because of a lack of fog during the FAA tests at the Arcata-Eureka airport, the project was moved to the nearby Redwood Creek Valley, where fog was more frequent in occurrence. Figure 2i (pg. 12) illustrates

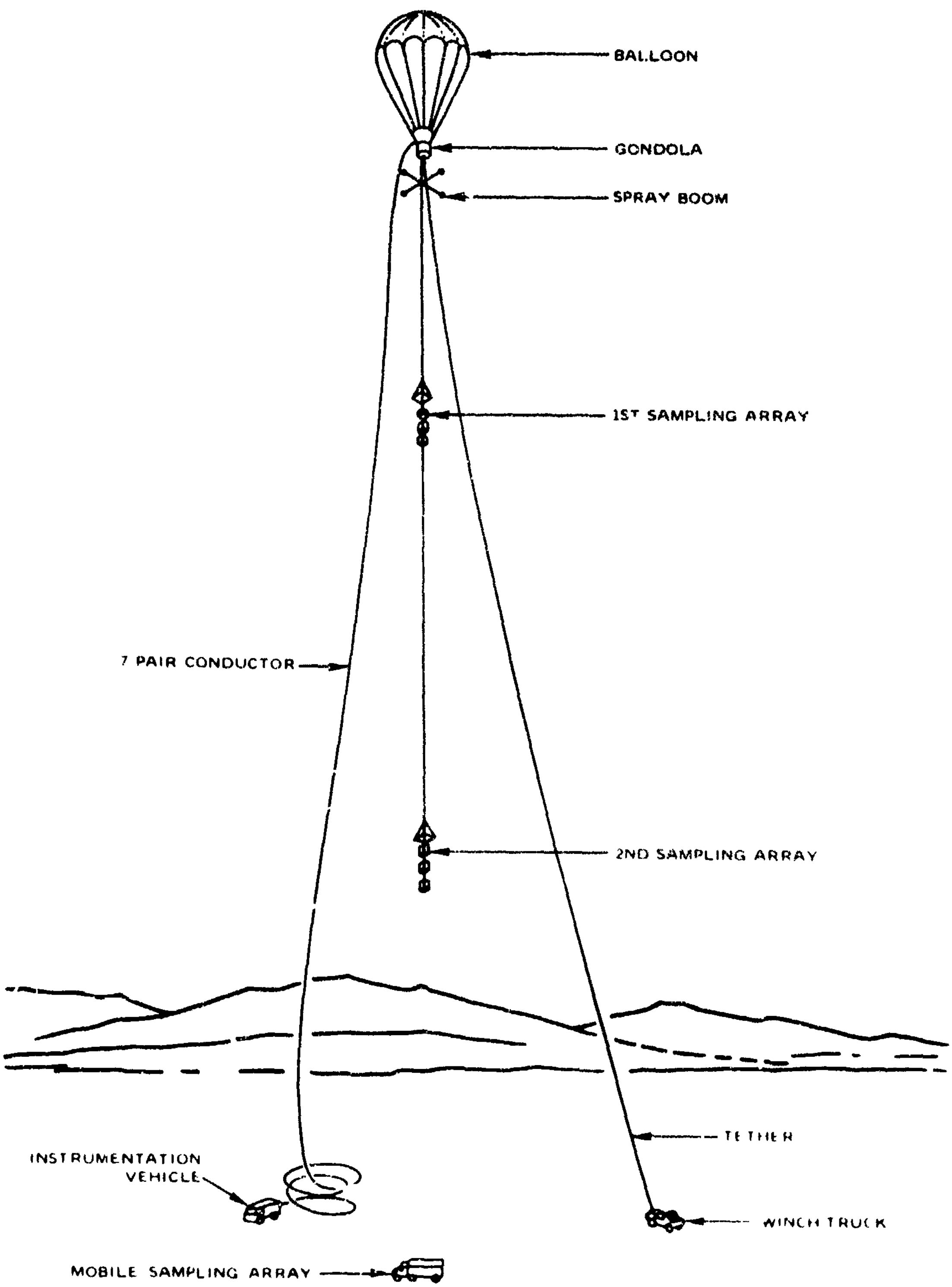


Figure 1. Hot-air balloon system.

the portion of the valley where the tests were conducted. Because of a lack of fog at this locality we were able to conduct one test only, using glycerine. A series of clear-air tests was conducted with all three chemicals.

This report discusses the clear-air tests and the fog-abatement test. The results include an analysis of glycerine as a fog-abatement agent. Preliminary conclusions are reached on how glycerine compares with the NWC ammonium nitrate-urea-water solution in improving visibility in fog.

CLEAR-AIR TESTS

A series of clear-air tests was conducted using the hot-air balloon system. The objectives of the tests were to measure the drop size-distribution and flow rate from the particulators, and to observe the characteristics of the plume. Results from these tests are summarized in Table 1.

Drop size-distribution measurements were made from the samplers hanging vertically below the balloon and from hand-held slices by surface observers. Samples obtained from the disc particulator showed that over 78% of all drops had diameters less than 30 μm and a median of 19 μm. These percentages remained constant regardless of the collection distance below the balloon. This result is in contrast to the lab results reported by McDuff, et al. (1971), which showed that 50% of the drops were between 15 and 74 μm in diameter with a median of 40 μm. Additional calibration measurements of the disc particulator are necessary to resolve the contrasting lab and field results.

The flow rate from the disc particulator during the clear-air tests was a maximum of 2.7 gal/min.

McDuff, et al. (1971) observed characteristics of the plume during the clear-air tests. The plume was approximately 10 feet in diameter immediately below the particulator which was at 100 feet AGL. In calm wind conditions the plume was observed to diffuse to approximately 20-25 feet in diameter. As the wind velocity increased to 2 to 3 knots the width of the plume increased to approximately 220 feet at the ground.

Table 1

Results from Clear Air Tests

Date	Fluid Temp (°C)	Material	Press (psig)	Calculated Flow Rate (gal/min)	Particulator*	RPM	Drop size-Distribution				Median No Dia.
							<30μm	30-60μm	60-100μm	>100μm	
11/2/71	50	Glycerine	25	2.7	Disc.	6600	74%	17%	3.5%	5.5%	18μm
11/2/71	26	Glycerine	20	2.7	Disc.	6600	83%	15%	1%	1%	19μm
11/2/71	23	Tetraeth.Gly.	50	0.8	Disc.	6600	Plume drifted away from samplers				
11/2/71	33	Dieth.Gly.	--	1.1	Disc.	6600	Plume drifted away from samplers				
11/3/71	30	Glycerine	50	0.2	RSI	5600	100%	0%	0%	0%	8μm
11/3/71	--	Glycerine	100	1.7	RSI	6000	Plume drifted away from samplers				

*A complete description of the Dow particulators is given by McDuff, et al., (1971).

FOG ABATEMENT TEST

Testing of the Dow fog-abatement chemicals with the balloon system commenced on 4 November 1971; a stratus deck filled the valley (base approximately 250 feet AGL, top approximately 500 feet AGL). The balloon, loaded with glycerine at 30°C and 20 psig, was launched at 9:33 PST. The balloon stabilized at roughly 450 feet AGL and began spraying at 9:47:30. The first significant observation from the ground indicated holes in the stratus developing around the balloon. These holes were attributed to the heat from the balloon. The next significant observation was made 3 minutes after spraying began; observers, both on the ground and in the balloon, noted that the particulator mist appeared to be reacting with the fog. A hole appeared in the fog below the balloon. The size of the hole was approximately 200-300 ft long, 100 ft wide and 250 ft in depth. By the end of the spraying at 9:56:50, 12.5 gallons of glycerine had been dispensed. The balloon was lowered at this time to eliminate any further possible effects it might have had on the cloud. The balloon was on the ground by 10:02. At this time a general breakup of the stratus layer had started.

The photographs of the test area from the Navy U-3 aircraft are illustrated in Figure 2. The balloon is in the center of each picture. The spraying had been under way for 4 minutes by the time the first photo was taken at 9:51:30 (Fig. 2a). The balloon is clearly visible and no holes are apparent either around or under the balloon. The shadow of the balloon on the top of the stratus layer can be seen.

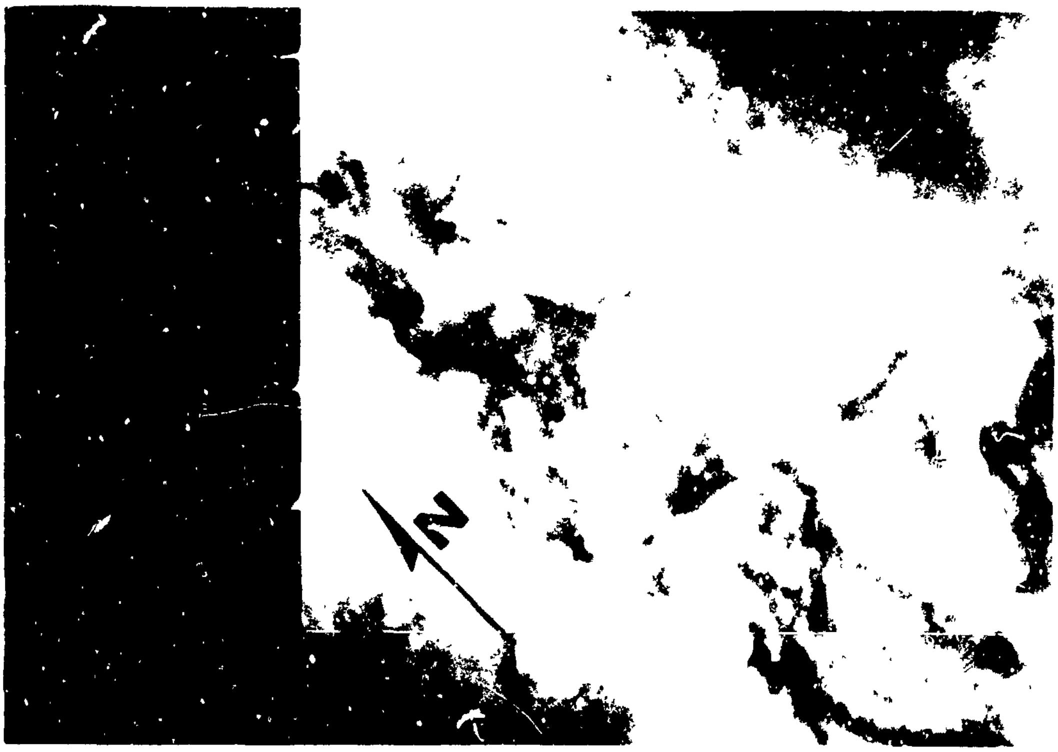


Fig. 2a   9:51:30

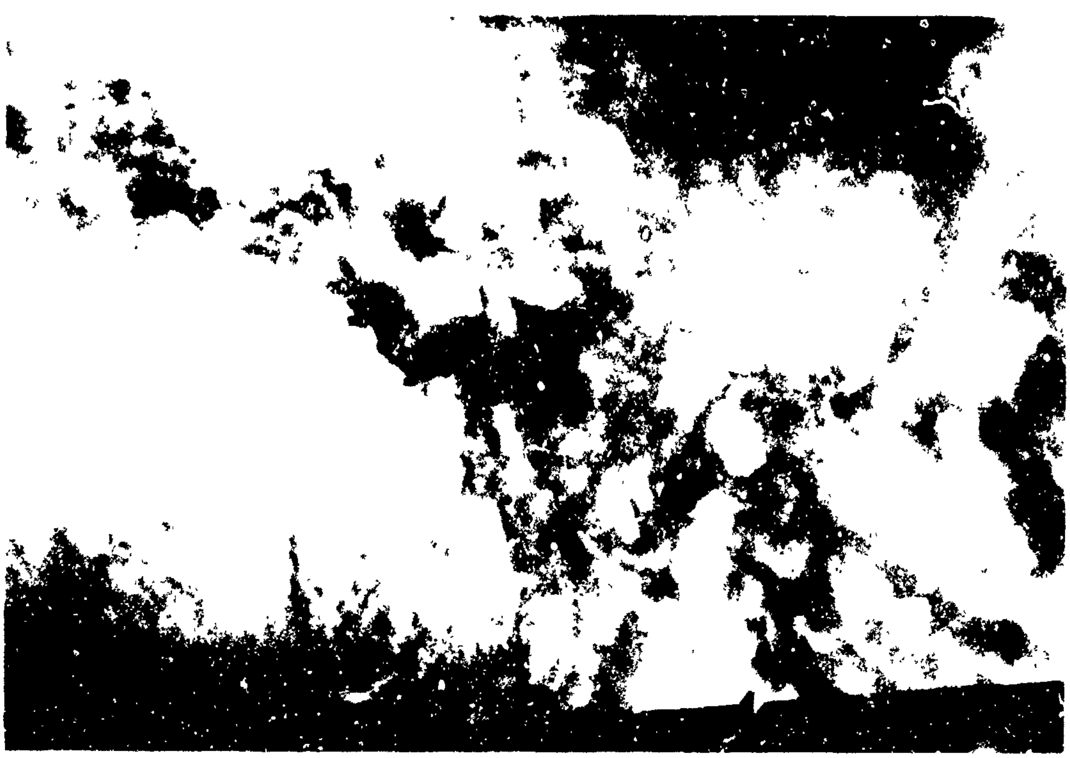


Fig. 2b   9:51:52

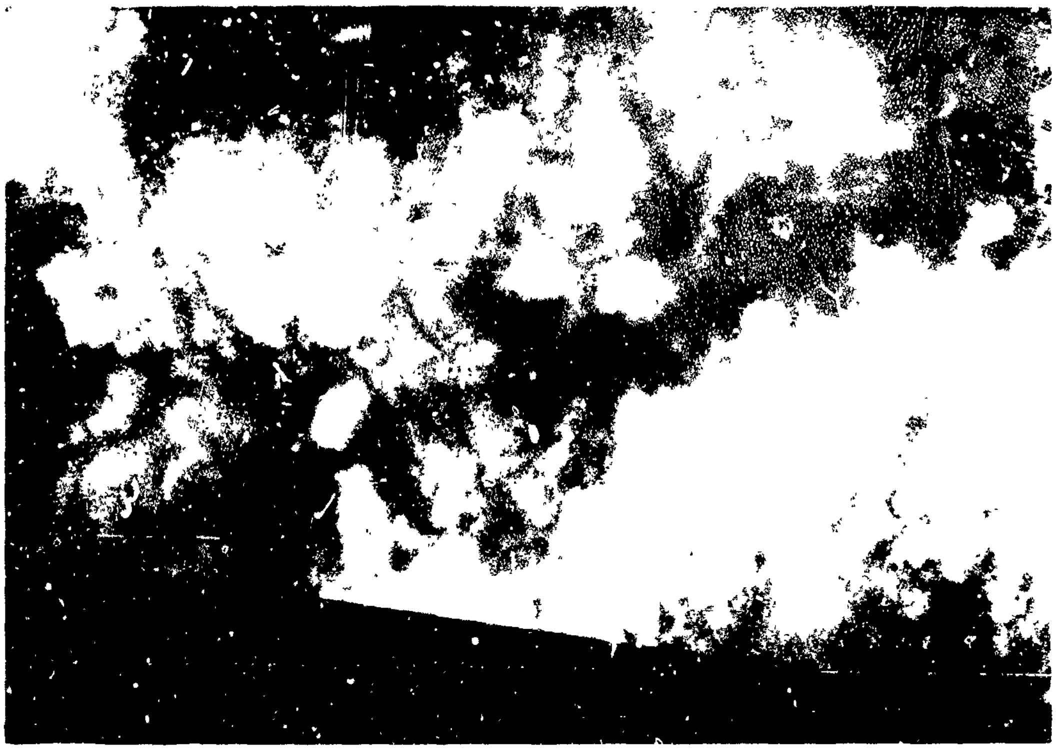
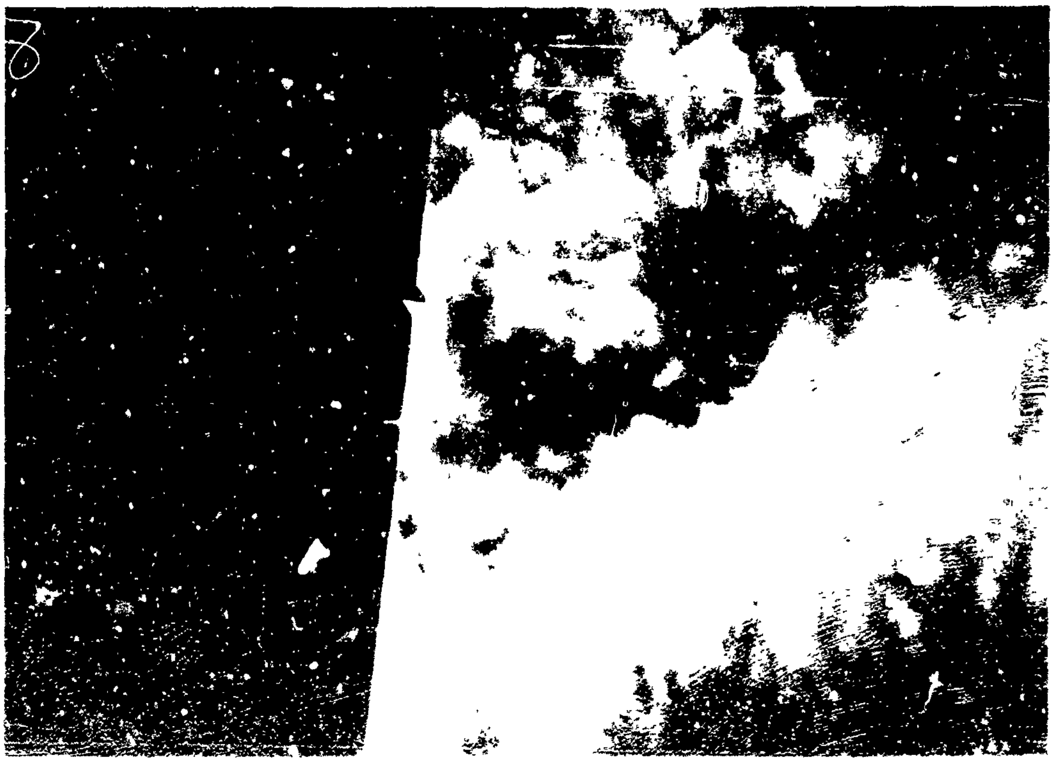


Fig. 2c 9:52:10



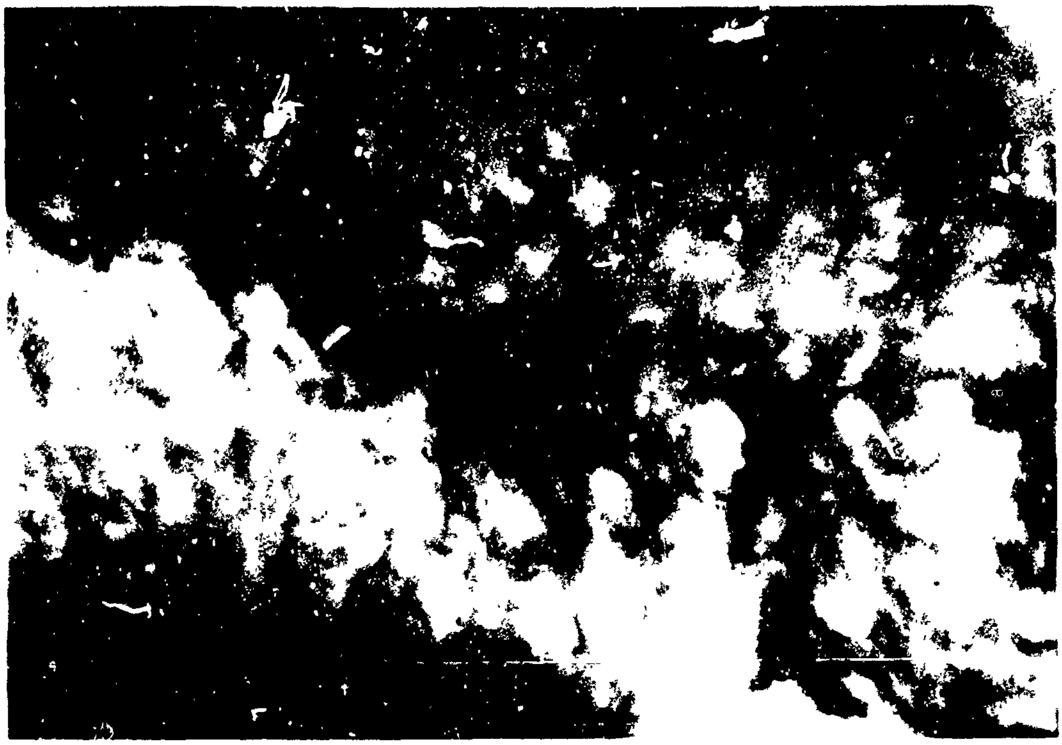
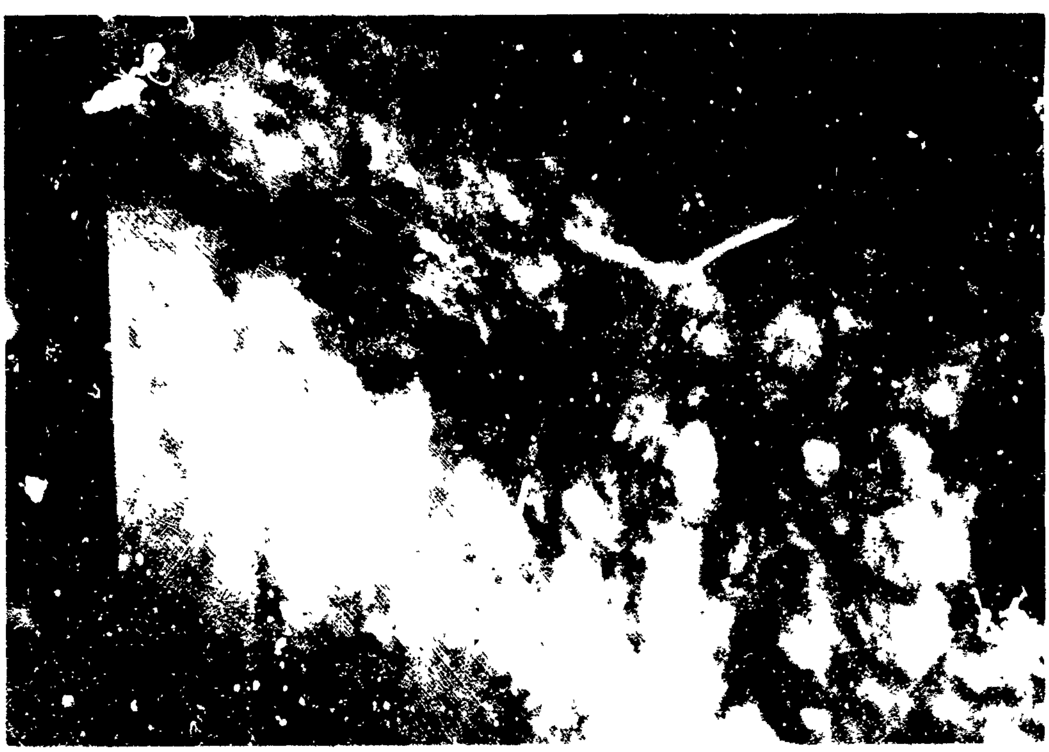


Fig. 2e   9:54:05



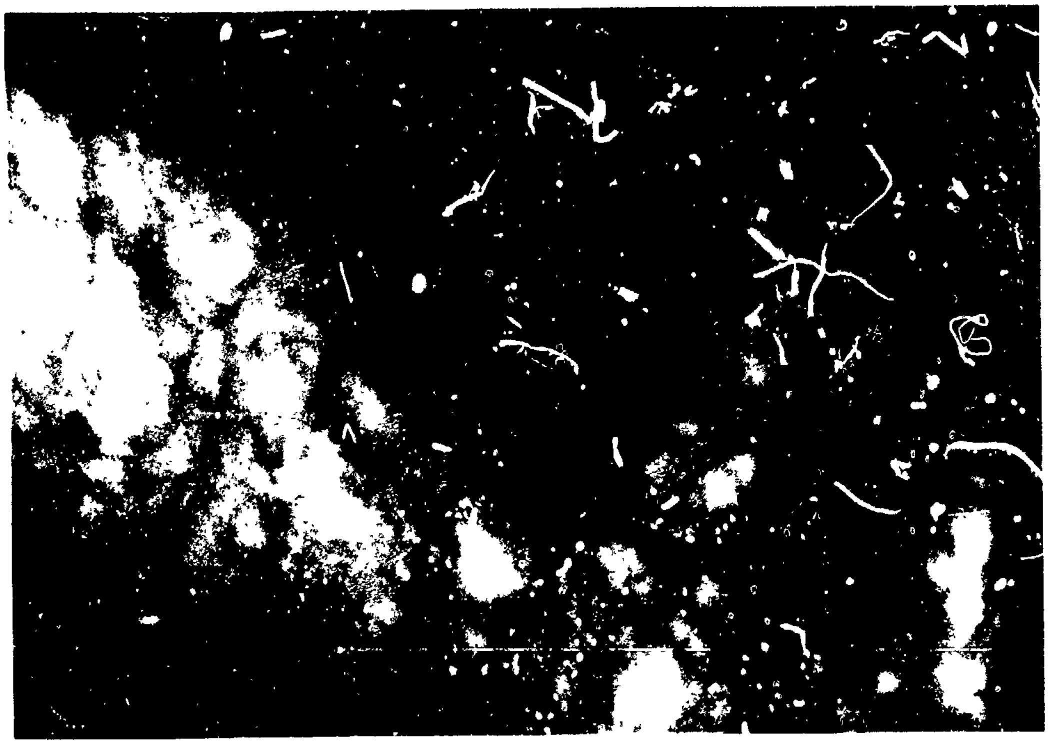


Fig. 2g 9:58:05

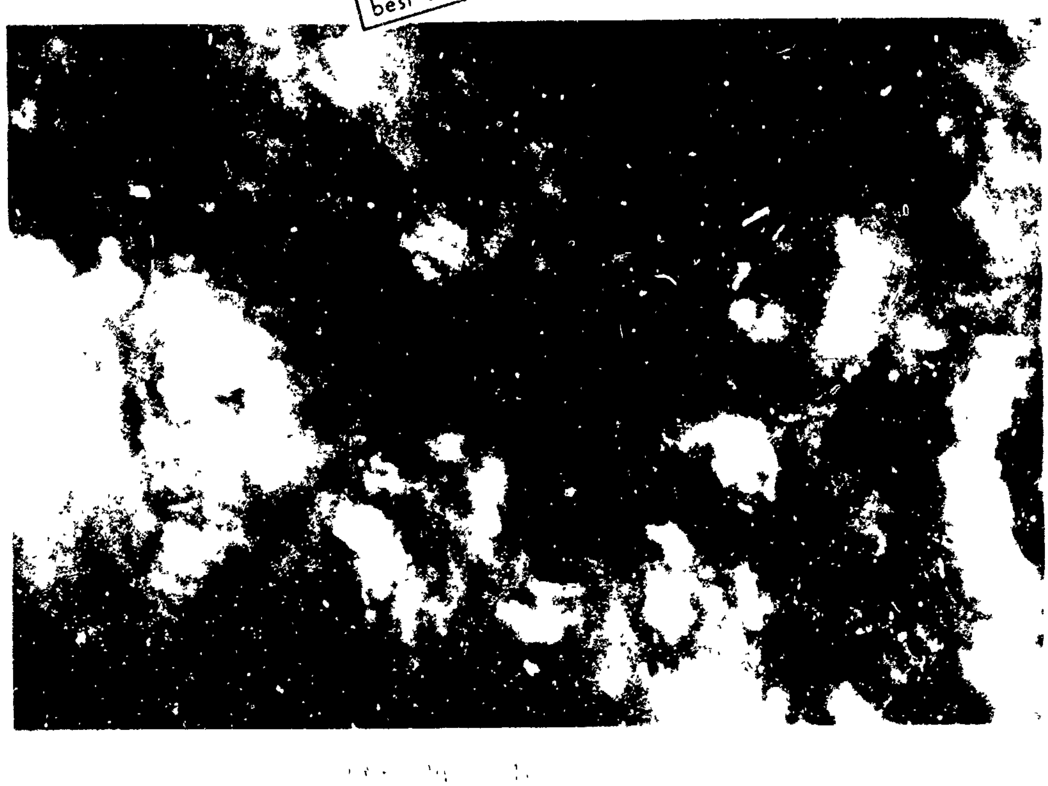


Fig. 21   9:58:44

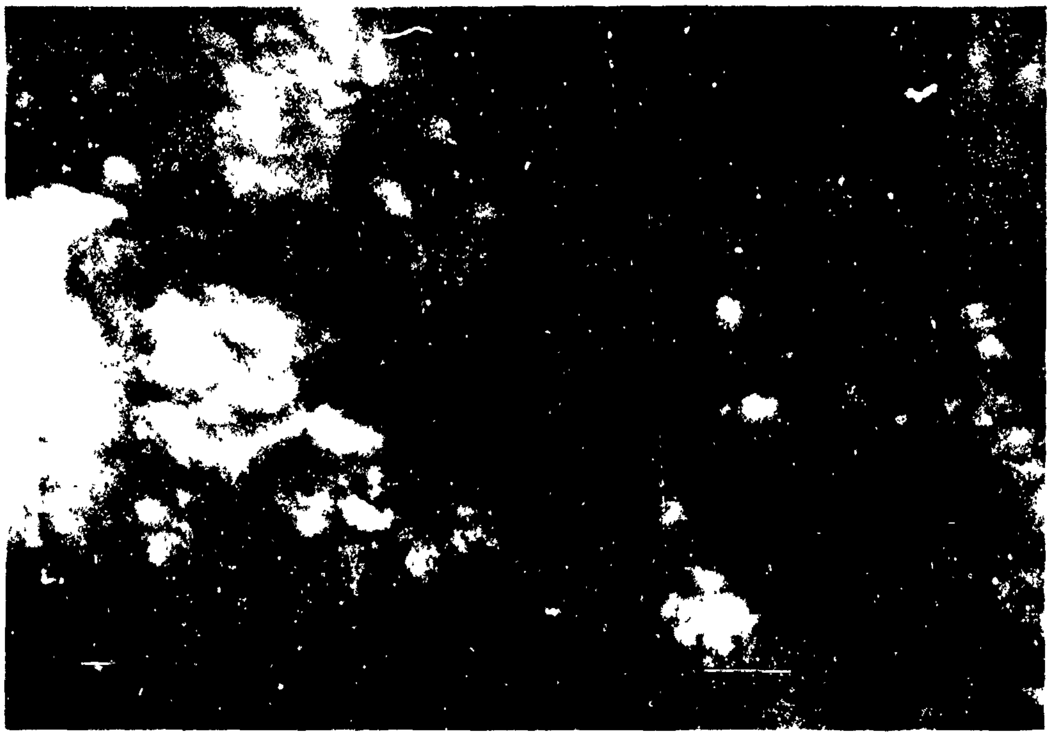


Fig. 2j 10:06:48

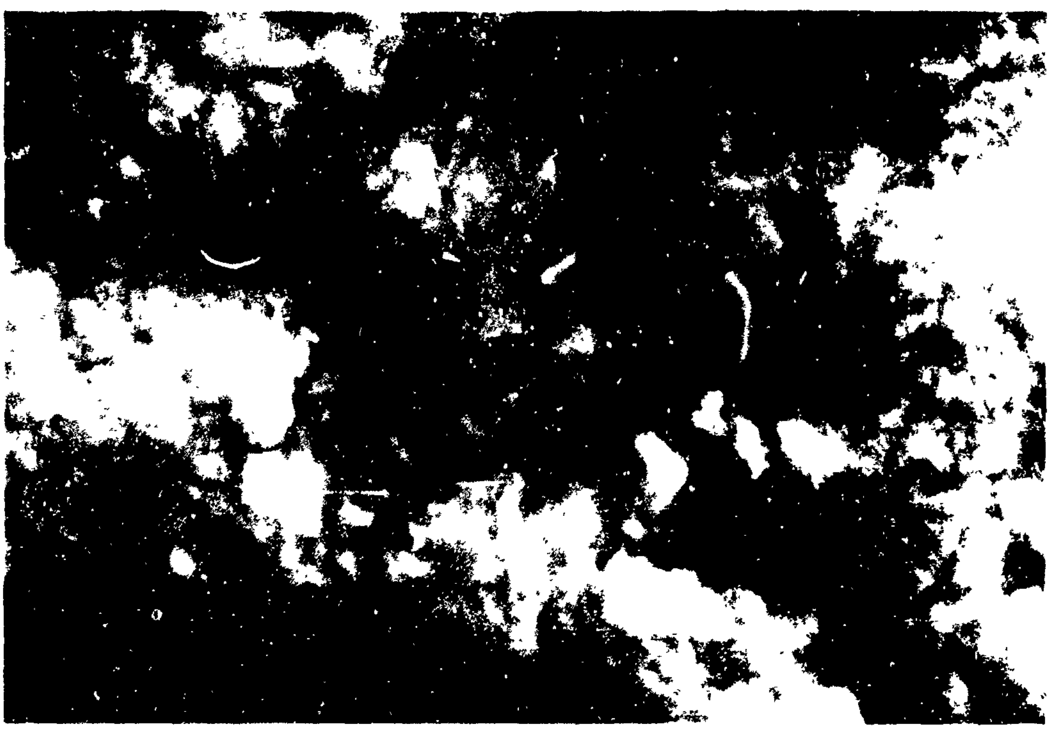


Fig. 2k 10:11:02

Fig. 21 10:07:40

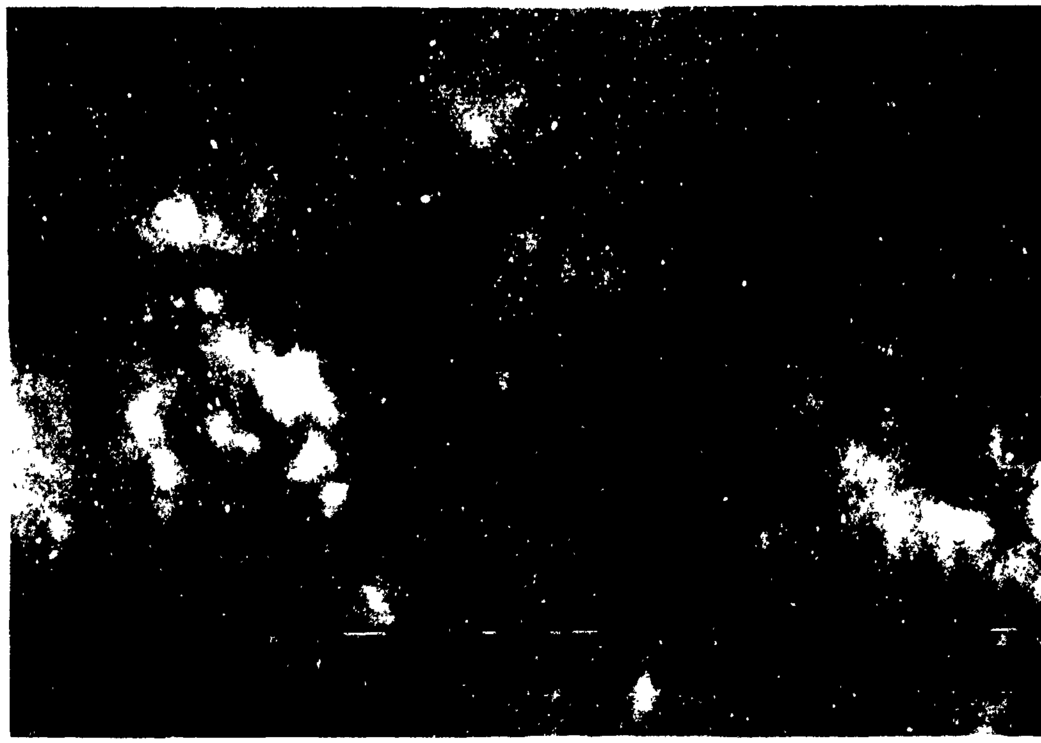


Fig. 2m 10:17:55

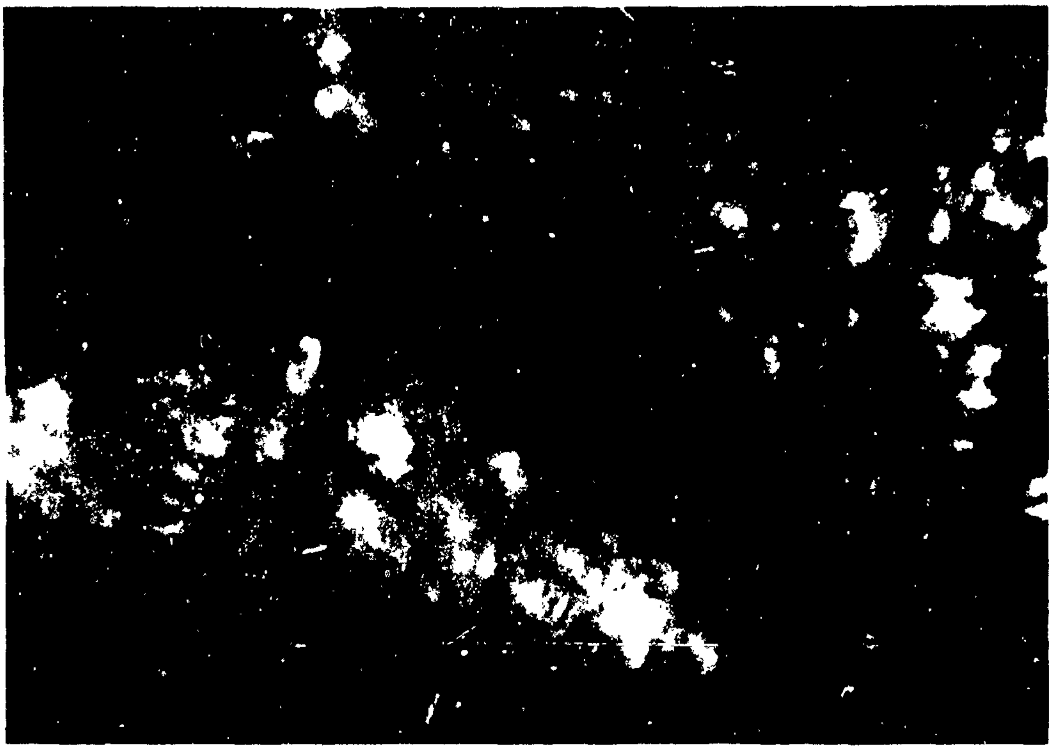


Fig. 2o 10:28:43

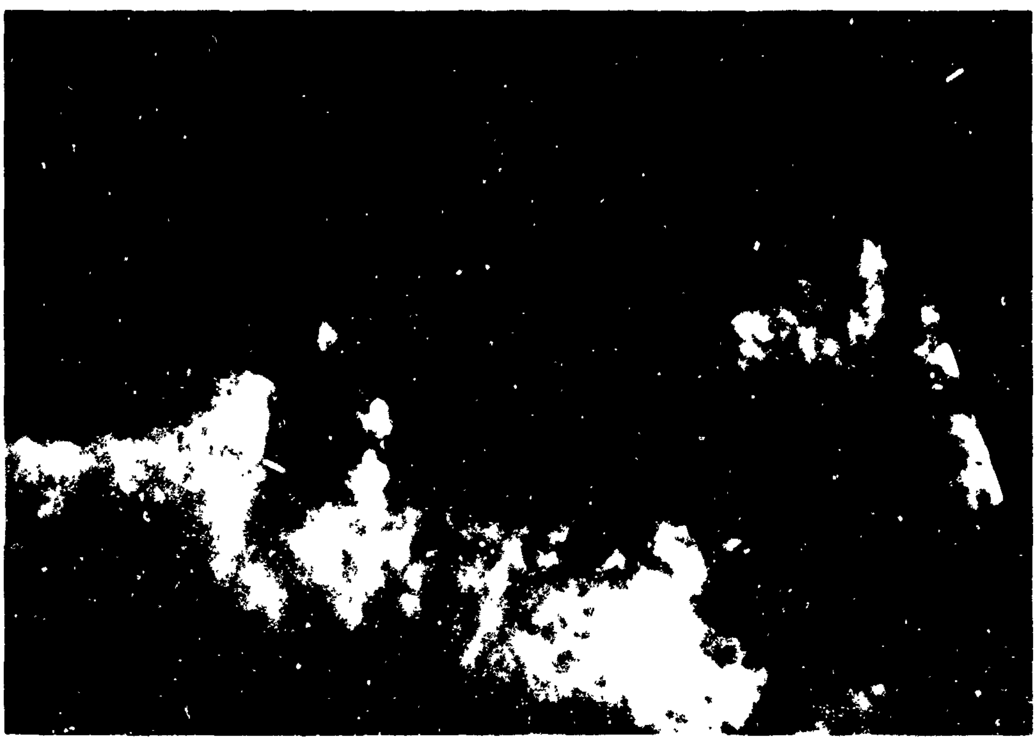


Fig. [illegible]

Figure 2b, 22 seconds later, appears similar. Apparently the heat from the balloon caused the observed large depression around the balloon in Figure 2a and 2b. By 9:52:10 (Fig. 2c) the first hint of a hole near the balloon can be seen. This hole occurred 4 min 30 sec after commencement of the chemical spray. The hole widened as shown in Figure 2d at 9:53:47, and an extended trough began to form. The hole, attributed to chemical spraying can still be observed near the balloon at 9:54:05 and 9:54:24 as shown in Figures 2e and 2f. The trough cutting diagonally across Figure 2g was well developed by 9:58:05. A generalized breakup of the stratus layer which was beginning made it difficult to separate the artificial clearing from the natural clearing. Large area photographs (Figures 2i and 2l) illustrate the clearing along the center of the valley. After the balloon returned to the ground the stratus deck filled over the balloon as shown in Figure 2j, taken at 10:06:48. Patches of stratus obscured the balloon at 10:11:57 (Fig. 2k) and at 10:17:55 (Fig. 2m). The filling-in correlated with the cessation of the spraying and the absence of the heat source from the balloon. Clearing proceeded rapidly after 10:17:55 as shown in Figures 2n, 2o, and 2p.

The treatment drops settling from the stratus deck were captured on hand-held slides by ground observers. The samplers on the cable were not used during this test. The average drop size-distribution was computed from these slides and is presented in Table 2. The resulting distribution had a majority of drops below 30 μm in diameter and the remainder above 100 μm. This result is in part supported by the results

Table 2

Glycerine Drop Size-Distribution
From the Fog-Abatement Test

Slide Exposure Time After Spraying Began (Min.)	No. Drops/ 100 mm^2	Median No. Dia. (μm)	Drop Size-Distribution < 30 μm	30-60 μm	60-100 μm	> 100 μm
2	27	24	60%	20%	3%	17%
3	11	29	47%	12%	0%	41%
4	23	19	69%	0%	0%	31%
5	55	19	53%	3%	3%	41%
Averages	29	2[illegible]	57%	9%	1%	33%

from the clear-air tests in Table 1. These results showed a majority of the drops below 30 μm. The large percentage of glycerine drops above 100 μm in the fog abatement test suggests that the droplets grew by condensing moisture from the evaporating fog drops and/or collecting the fog droplets.

DISCUSSION

The results from the fog-abatement test indicate that the following four factors could have affected the rate of dissipation:

(1) Natural clearing

(2) Collection of fog drops by glycerine drops

(3) Evaporation of fog drops by glycerine drops

(4) Heat from the balloon

It is possible the natural clearing was taking place througout the entire test. During the test,portions of the other factors were operative. The magnitude of each of these factors was calculated to determine the dominant process.

McDuff, et al. (1971) concluded that "Glycerine is an effective coalescence reagent for water mist suspended in air (warm fog)". We interpret their conclusion to be that the larger glycerine droplets collect the smaller fog droplets because of the difference in their fall velocities. The extent this process contributed to the observed fog clearing was investigated by calculating the probability of the glycerine drops sweeping out the fog drops. The probability that a point on the surface of the stratus deck was hit by a glycerine drop is expressed by a/A where a is the effective sweep-out area under a falling glycerine drop and A is the cross-sectional area of the stratus deck on which the glycerine drop is falling. The probability that a glycerine droplet will not hit the point is given by 1 - (a/A). The probability (p) that, of y droplets

hitting A, at least one will hit the point equals one minus the probability that, of y droplets hitting A, none will hit the point:

$$p = 1 - (1 - (a/A))^y \tag{1}$$

For values of $y \gg 1$, (1) simplifies to

$$p = 1 - e^{-ya/A}. \tag{2}$$

The term y in (2) was computed by dividing the total mass of glycerine released ($5.85 \cdot 10^4$g) by the mass of a 40 μm diameter glycerine drop ($2.38 \cdot 10^{-8}$g) resulting in $2.46 \cdot 10^{12}$ drops. Here an assumption was made that the glycerine spray consisted of 40 μm drops. This size was established from data in McDuff, et al. (1971).

The term a in (2) was computed from the following expression,

$$a = \pi\ (r_s + r_f)^2\ e \tag{3}$$

where r_s is the radius of the glycerine droplets (20 μm, r_f is the radius of the fog droplets (assumed 5 μm), and e is the collection efficiency of r_s fir r_f (0.11 from Davis, et al., 1970). The value of a for these r_s and r_f values is $2.15 \cdot 10^{-6}$ cm^2.

The term A in (2) was computed using the observations made during the fog abatement test. Assuming the plume opened the 178 ft diameter hole observed from the ground during the fog abatement test, the value for A equals $2.3 \cdot 10^7$ cm^2.

Substituting the values for a, y, and A into (2) results in a value for p of 0.21. This result indicates that spraying $5.85 \cdot 10^4$g of 40 μm glycerine drops over an area 178 ft in diameter will result in 21% of the drops being swept out. The glycerine would not have collected 79% of the fog drops. The dosage corresponding to these calculations is 21 gal/acre. Additional calculations showed that 99% of the drops would have been swept out if the dosage was increased to 1100 gal/acre. Furthermore, keeping the dosage at 21 gal/acre and changing the glycerine drops to 19 μm (corresponds to diameter from clear-air tests), the p from (2) would be improved to 0.49. The 21 and 49% sweep-out figures suggest that the observed hole during the test could not be explained by defining glycerine as soley a "fog coalescence reagent".

The extent of the observed fog clearing due to the hygroscopicity of the glycerine droplets can be estimated. The glycerine droplets are hypothesised to reduce the relative humidity of the stratus layer. Simultaneously the fog droplets evaporate to restore the relative humidity. These visibility improvement processes have been the basis for most recent fog abatement work (see Jiusto, et al., 1968 and Tag, 1971). Clark, et al.(1971) have constructed a computer model which is valid for predicting the growth of an ammonium nitrate-urea-water droplet in a warm fog. This model was expanded to predict the growth of glycerine droplets by incorporating vapor-pressure data of a glycerine-water mixture from Frazer, et al. (1928), density data for the mixture from Bearce, et al. (1928), and surface-tension data for the mixture

from Young and Harkins (1928).

The model was employed to estimate the growth of 40 μm ammonium-nitrate-urea-water droplet and 40 μm glycerine droplets in a warm fog. The 40 μm size is the size we computed from the results of McDuff. et al. (1971). The modeled fog consisted of 10 μm droplets and a liquid water content of 0.1 g m^{-3} (conditions assumed to exist during the fog-abatement test). The results of the droplet growth in fogs of 95% and 100% relative humidity are illustrated in Figures 3a and 3b, respectively. The results indicate that 40 μm diameter glycerine droplets can grow significantly in a warm fog. The ammonium nitrate-urea-water droplets grow better than glycerine drops in both the 100% and 95% fogs.

The calculations were repeated for 19 μm ammonium nitrate-urea-water droplets and 19 μm glycerine droplets. These sizes conform to the median diameter measured from the particulator during the clear-air tests. The calculated increase in diameter of both types of 19 μm drops is the same as the increase for the 40 μm drops in a 100% fog. Both types of 19 μm drops grow less than 40 μm drops in a 95% fog. The results of these calculations may explain the larger percentage of drops above 100 μm in the fog-abatement test than in the clear air tests.

The amount of fog water transferred to a glycerine droplet (initially 40 um) and an ammonium nitrate-urea-water droplet (initially 40 μm) by condensation and by collection is illustrated in Figure 4. Here it is shown that both types of droplets grow mainly by condensation and not by collection. This result is in agreement with the previous sweep-out calculations where it was found that the observed hole could not be explained by coalescence alone. The calculations

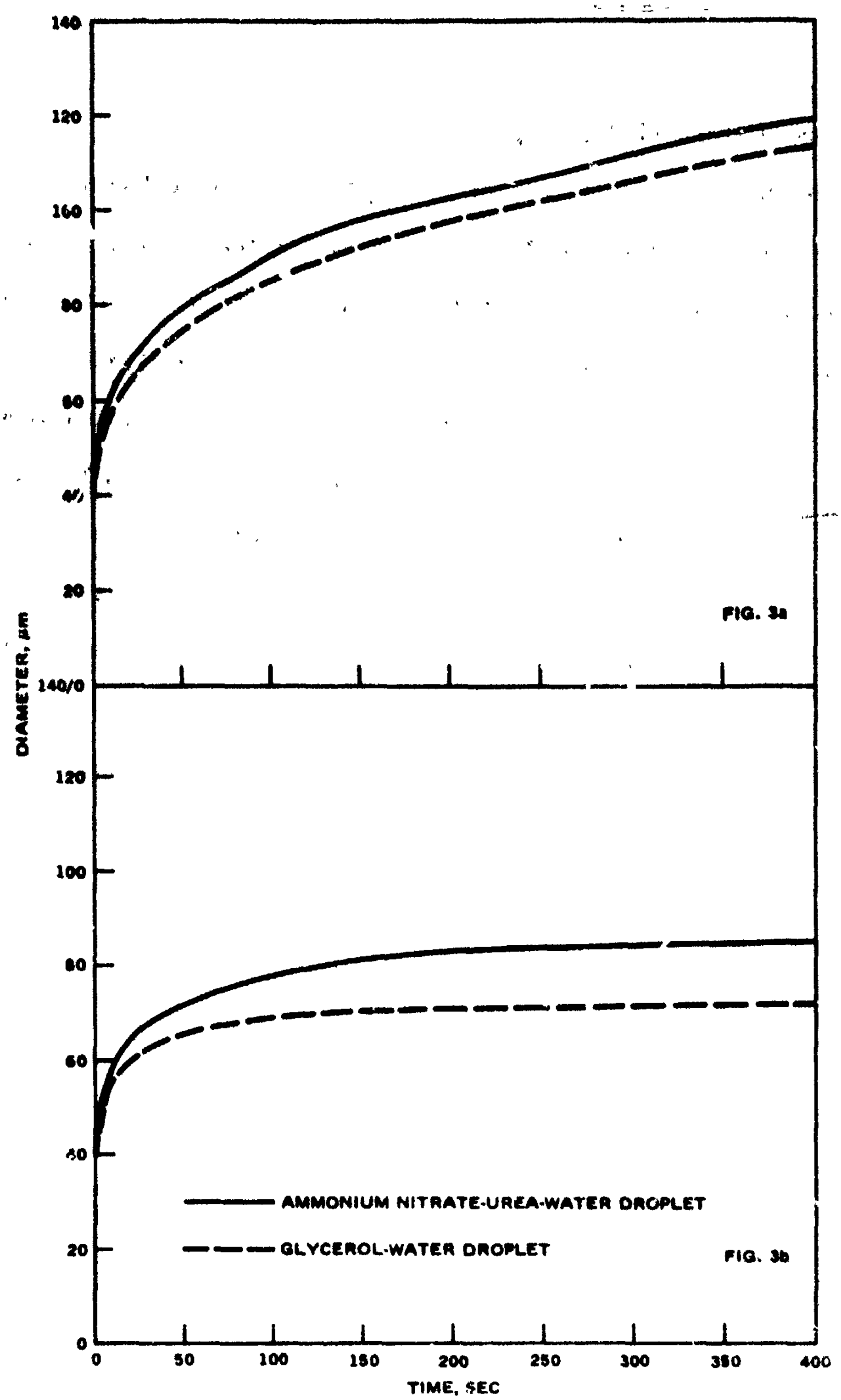


Figure 3. Simulated growth of a solution droplet initially 9 parts by weight ammonium nitrate-urea to 1 part water (——) and a solution droplet initially 99% glycerol and 1% water (---). The droplets were simulated to grow in a fog of 10 µm dia. droplets, 0.1 g m^{-3} liquid water, and 95% (Fig. 3b) and 100% (Fig. 3a) humidity.

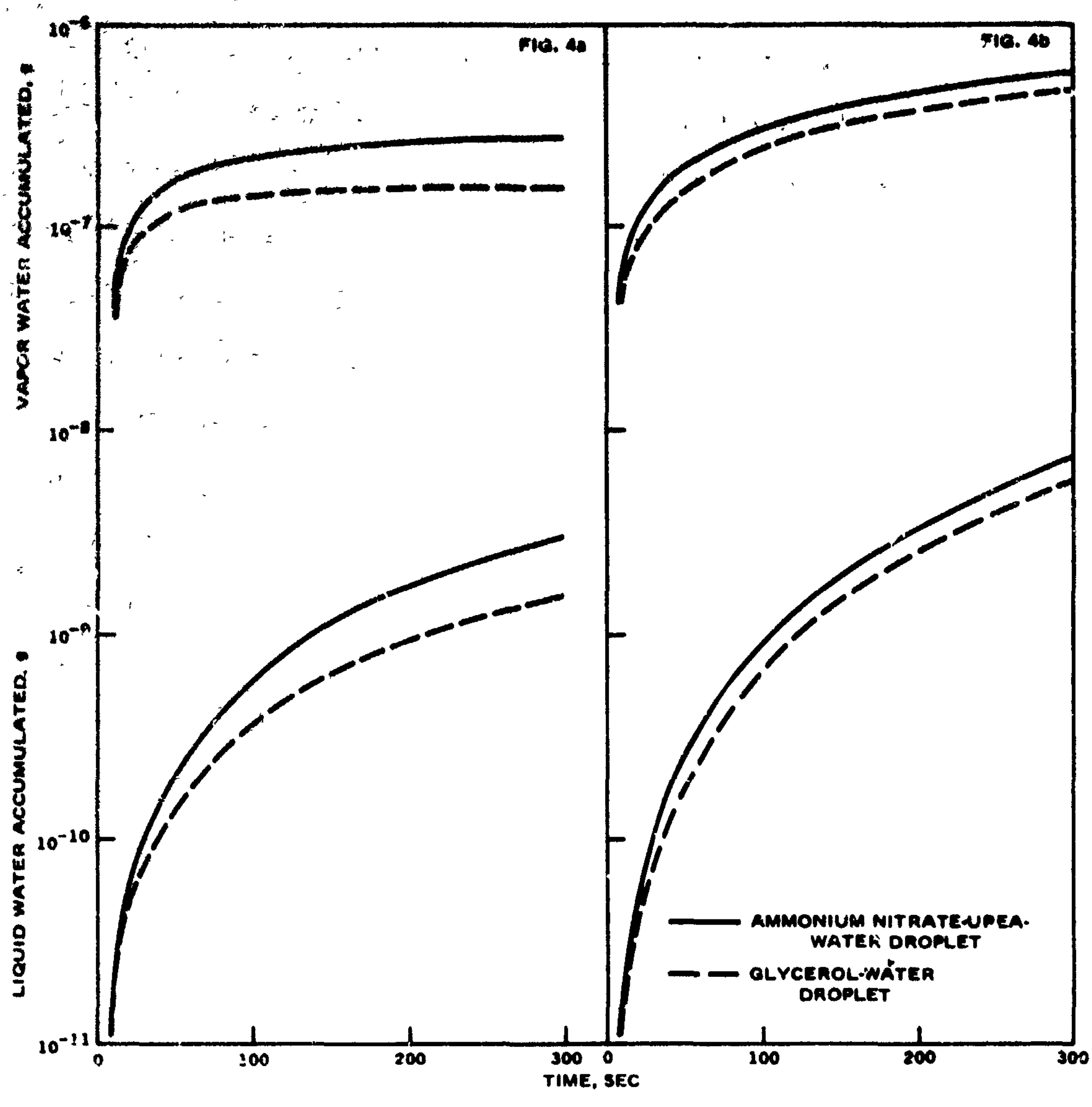


Figure 4. Simulated mass of liquid water and vapor water accumulated by an ammonium nitrate-urea-water droplet (—) initially 40 μm dia. and a glycerol-water droplet (---) initially 40 μm dia. The droplets were simulated to grow in a fog of 10 um dia. droplets, 0.1 g m^{-3} liquid water, and 95% (Fig. 4a) and 100% (Fig. 4b) humidity.

were repeated for both types of droplets with initial diameters of 19 μm. Both types increased in mass the same amount as the 40 μm drops in the 100% fog. Both types grew significantly less than the 40 μm drops in the 95% fog.

The amount of water transferred from the fog droplets to the glycerine droplets will be estimated. The stratus deck was assumed to contain 0.1 g m^{-3} of water at 100% relative humidity. The hole cleared in the deck by the glycerine droplets was estimated to be 178 feet in diameter and 200 feet deep ($1.41 \cdot 10^{11} cm^3$). The amount of glycerine released into the deck ($5.85 \cdot 10^4 g$) was assumed to be uniformily dispersed in the cleared volume. Thus the amount of glycerine in each m^3 of that volume was 0.4 g ($5.85 \cdot 10^4 g/1.41 \cdot 10^{11} cm^3$). The results in Figure 4b indicate that each glycerine drop (initial size 19 μm) would have increased its mass one order of magnitude as it settled through the 200 foot stratus deck. This magnitude indicates that the 0.4 g m^{-3} of glycerine can pick up 4.0 g m^{-3} of fog water. Since 0.1 g m^{-3} of fog water was available, this amount was completely exhausted by the glycerine. The hole in the stratus deck therefore can be explained primarily by the evaporation of fog drops by glycerine drops and secondarily by the collection of fog drops by glycerine drops.

The extent of the observed fog clearing due to heat from the balloon was estimated using information provided by Feit, et al. (1970). They calculated that to evaporate 0.1 g m^{-3} of fog water at 3^oC (observed temperature at the start of the fog-abatement test) and reduce the relative

humidity from 100% to 95% it would require each cubic meter of fog to be heated with 440 calories. The volume of fog the balloon heated was approximated from the observer's notes. The balloon was half in and half out of the fog when the balloon stabilized at 9:47:30 (the balloon is 90 feet tall). Assuming a drift of approximately 0.6 m sec^{-1} (fall out was observed 366 m away from the balloon in 560 seconds) the volume of fog heated by the balloon during the 560 sec duration of the spray was $1.3 \cdot 10^5$ m^3. From information provided by Craig (1972), pilot of the balloon, the balloon releases roughly $3 \cdot 10^6$ btu/hr in tethered flight. This figure translates into $1.26 \cdot 10^7$ cal min^{-1}, but only one-half of the balloon was heating the volume. One-half of the balloon released $5.9 \cdot 10^7$ cal during the 560 sec spray period. Each cubic meter of fog that drifted by the balloon was heated with 453 cal ($5.9 \cdot 10^7$ cal/$1.3 \cdot 10^5$ m^3). This amount of heat is remarkably similar to the 440 cal/m^3 computed by Feit, et al. (1970). Heat from the balloon, therefore, was the most probable cause of the large depression around the balloon observed in Figures 2a and 2b.

An anomaly was observed during the testing; the glycerine droplets fell at approximately six times the velocity predicted by Stokes Law. This anomaly has been previously reported by Himel (1969). Mathews (1970) has noted the possibility that drag on individual droplets is reduced significantly when a large number of droplets are close together.

CONCLUSIONS

Planned objectives for testing three Dow fog-abatement chemicals were not met because of a lack of suitable test conditions during the scheduled testing period. While clear-air tests were conducted using all three candidate agents, only one fog-abatement test was conducted. Glycerine was tested on this occasion.

Results from this test indicated that the heat from the hot-air balloon cleared the top 50 feet of the 250 foot deep stratus deck. A hole was cut through the remaining 200 feet by the glycerine.

Calculations demonstrated that the glycerine could not have cleared the observed hole solely by sweeping-out the fog droplets. The amount of glycerine would have had to be increased from 21 gal/acre to 1100 gal/acre to clear a hole by this process.

Calculations also demonstrated that the glycerine could have cut the hole in the fog by a well known process: evaporation of fog droplets by hygroscopic droplets. The amount of glycerine employed in th test was estimated to be 21 gal/acre. Successful visibility improvements in warm fogs have been produced by NWC using 13 gal/acre of ammonium nitrate-urea-water solution (see Hindman, 1972). Glycerine was calculated to be nearly as hygroscopic as the ammonium nitrate-urea-water solution in fogs of 100% relative humidity, and less hygroscopic in fogs of 95% relative humidity.

Analysis of the hand-held slides illustrated that these slides can be used to capture settling fog and glycerine droplets.

REFERENCES

Bearce, H. W., G. C. Mulligan, and M. P. Maslin, 1928: Density of certain aqueous organic solutions. Int. Crit. Tables, 3, 115-122.

Blomerth, E. A., R. S. Clark, H. E. Cronin, J. R. Ennis, R. L. Lininger, D. W. Reed, P. St.-Amand, W. C. White, and T. L. Wright, 1970: Project Foggy Cloud I. NWC TP 4929, Naval Weapons Center, China Lake, Ca.

Carroz, J. W., P. St.-Amand, D. R. Cruise, 1972: The use of highly charged hygroscopic drops for fog dispersal. Submitted to the J. of Wea. Mod.

Clark, R. S., L. A. Burkardt, and J. W. Carroz, 1971: Properties of ammonium nitrate-urea-water hygroscopic reagent for warm fogs. NWC TP 5190, Naval Weapons Center, China Lake, Ca., 26 pp.

Craig, J., 1972: Personal communication.

Davis, M. H., J. D. Klett, and M. Neiburger, 1970: Collision efficiencies of cloud droplets at small Reynolds Numbers. Preprints - Conf. on Cld. Phys., 24-27 Aug. 1970, Ft. Collins, Colo., 115-116.

Feit, D. M., E. E. Hindman, II, D. B. Johnson, and P. M. Tag, 1970: Warm fog dispersal techniques. NAVWEARSCHFAC TP No. 1-69 (REv), 46 pp. (On file at Environmental Prediction Research Facility, Monterey, Ca.).

Frazer, J. C. W., R. K. Taylor, and A. Grollman, 1928: Two-phase liquid-vapor isothermal systems, vapor-pressure lowering. Int. Crit. Tables, 3, 292-293.

Himel, C. M., 1969: The physics and biology of the control of cotton insect populations with insecticide sprays. J. Ga. Entomol. Soc., 4, 33-40.

Hindman, E. E., II, 1972: Meteorological conditions for artificial dissipation of warm fog. To appear in Preprints -3rd Conf. on Wea. Mod. 26-29 June 1972, Rapid City, S. D.

Hindman, E. E., II, 1972a: Microphysical structure of warm fog. Submitted for presentation at the International Cloud Physics Conference, 21-26 August 1972, London, England.

Hindman, E. E., II, R. S. Clark, and T. L. Wright, 1972: Project Foggy Cloud IV, Phase I - Evaluation of warm fog dissipation techniques. NWC TP in preparation.

Jiusto, J. E., R. J. Pilié, and W. C. Kocmond, 1968: Fog modification with giant hygroscopic nuclei. J. Appl. Meteor., 7, 860-869.

Loveland, R. B., J. G. Richer, M. H. Smith, and R. S. Clark, 1972: Project Foggy Cloud IV, Phase II - Warm fog modification by electrostatically charged droplets. NWC TP 5338, 30 pp.

McDuff, J. M., J. L. Dunn, Jr., Z. J. Moore, and E. L. Pendleton, 1971: Evaluation of chemicals for warm fog abatement. The Dow Chemical Co., USA, Texas Division, Freeport, Texas, Report prepared for DOT-FAA, Washington, D.C., 67 pp.

Mathews, L. A., 1970: Dynamics of small spheres moving at low subsonic velocities in low density air. PhD dissertation, Dept. of Chem. Eng., U. of Utah, Salt Lake City, Utah.

White, W. C., R. S. Clark, H. E. Cronin, J. R. Ennis, D. W. Reed, and T. L. Wright, 1969: Project Tule Fog: An investigation of warm fog dispersal using hygroscopic solutions. NWC TP 4766, Naval Weapons Center, China Lake, Ca., 16 pp.

Wright, T. L., R. S. Clark, and W. C. White, 1972: Project Foggy Cloud II - Experiments in warm fog dispersal. NWC TP 5267, Naval Weapons Center, China Lake, Ca., 31 pp.

Wright, T. L., R. S. Clark, and P. St.-Amand, 1972a: Project Foggy Cloud III, Phase I - Warm fog dispersal using hygroscopic solutions. NWC TP 5297, Naval Weapons Center, China Lake, Ca., 50 pp.

St.-Amand, R. S. Clark, T. L. Wright, and W. G. Finnegan, 1971: Warm fog modification, Proc. Int. Conf. Wea. Mod. 6-16 Sept. 1971, Australia, 259-264.

Tag, P. M., 1971: Results generated from a one-dimensional warm fog model which simulates hygroscopic seeding. NAVWEARSCHFAC TP No. 11-71, 63 pp. (On file at Environmental Prediction Research Facility, Monterey. Ca.).

Young, T. F., and W. D. Harkins, 1928: Surface-tension data for certain pure liquids between 0 and 360C and for all types of solutions at all temperatures. Int. Crit. Tables, 4, 446-447.